EXPERIMENTAL STUDY AND CFD SIMULATION OF TWO - PHASE FLOW (WATER – SOLID) IN FLUIDIZED BED COLUMN

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ABSTRACT :-

The static pressure of two phase (liquid - Solid) fluidized bed was investigated experimentally in this work for different values of the ratio static bed height over the diameter of the bed column (H/D) (0.59, 0.98, 1.38) and liquid phase velocity (0.16, 0.49, 0.82 m/s). As well as the expansion of the bed visualized experimentally has compared with the solid volume fraction found numerically. The fluidized system consists of glass test pipe of 1m height and 0.0254 m diameter inserted with stainless steel particles of 1.5 mm diameter fluidized by water. Pressure was measured by pressure sensor located at four tapes on the side of the fluidized bed pipe. High speed camera was used to photograph the flow in the test pipe. The experimental results compared with computational fluid dynamics model simulated by ANSYS FLUENT version 15.0. The results were in a good agreement with the experimental data.

Keywords - Fluidized bed, Two phase flow, CFD, Ansys fluent, Pressure

دراسة عملية ومحاكاة لأبراج التمييع ثنائية الطور (ماء- صلب)

الخلاصة :

تم دراسة الضغط في أبراج التمييع ثنائية الطور (سائل – صلب) عمليا في هذا البحث لكميات مختلفة من نسبة ارتفاع المادة الصلبة إلى قطر الأنبوب المستخدم للتمييع (H/D) (0.59، 0.98، 1.38) و سرعه الطور السائل (0.16، 0.49، 0.82 m/s). كذلك تمت مشاهده ارتفاع المادة الصلبة داخل الانبوب عمليا ومقارنتها مع النتائج النظرية للكسر الحجمي للمادة الصلب. النظام المستخدم للتمييع يتكون من انبوب شفاف بارتفاع ام و قطر 0.0254 م وبداخله حبيبات من مادة الفولاذ المقاوم للصدأ بقطر 1.5ملم والتي تم تمييعها باستخدام الماء. تم استخدام أربع متحسسات لقياس الضغط على طول انبوب التمييع. استخدمت كاميرا تصوير ذات سرعه عالية لتصوير الجريان داخل الأنبوب. تمت مقارنة النتائج العملية مع نتائج الموديل الرياضي ووجدت في حالة تطابق جيد .

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NOMENCLATURE :

CFD: Computational fluid dynamics
Fq: External force (N)
g: Gravity acceleration (m/s2)
Kp: Exchange coefficient
q: Number of phases
Q: Water flow rate
U: Superficial velocity (m/s)
mpq: Interphase mass exchange(kg/m3.s)
Greek symbols
ε: Epsilon
αq: Volume fraction for the qth phase
ρq: Mixture density for the qth phase (kg/m3)
τq: Shear stress for the qth phase
Subscripts
a: Air
c: Continuous phase (water)
lift: Lift force
νm: Virtual mass force

1. INTERODUCTION :-

High density solid particles suspended in a less density upward fluid flow are called fluidization. Fluidized bed system used in wide range of application environmental and food , refining, pharmaceutical, and chemical industries due to its attractive characteristics such as component extracting from liquid phase without any change in the properties of liquid or liquid treatment, in which heat and mass transfer are high between phases, and good particles mixing. Computational fluid dynamics (CFD) used by many researchers to predict the hydrodynamics of the fluidized bed using two approaches Eulerian- Eulerian and Eulerian Lagrange due to the complexities of the two phases motion and the interface between them is transient and unknown. **Fan et al.** studied the segregation and expansion of a liquid solid fluidized bed with binary solid particles using Eulerian – Eulerian model to simulate a laminar unsteady flow using two dimensional model. **Jang et al.** used computational fluid dynamic model to simulate gas solid bubbling fluidized bed with pharmaceutical particles by using a user defined function (UDF) to describe particle density, drying rate, and the thermal conductivity to the Fluent cod. **Kumar et al.** used fluent software to form computational analysis for a circulating fluidized bed combustion using pre mixed combustion and discrete phase model to describe two phase (gas -solid) mixture. **Ajay et al.** performed a two dimensional model to investigate how the minimum fluidization velocity is effected by the bed height for a two phase cylindrical fluidized bed. **Muthu Kumar et al.** used Eulerian multi fluid model incorporated with kinetic theory to investigate the flow pattern for a two phase fluidized bed reactor. **Moon et al.** performed 3D particle simulation for a vibrated gas solid fluidized bed with fine powder to study cyclic pressure formed by vibration. **He et al.** simulated discrete particle model along with turbulent phase for two phase fluidized bed riser to calculate the distribution of particles with arbitrary size. **Chemloul et al.** experimentally measured the velocity of particles for solid liquid fluidized bed using LDA technique and logic system of combustion electronic. **Bandaru et al.** used bed gradient pressure to determine the three phase inverse fluidized bed minimum velocity for liquid phase. **Song et al.** investigated the characteristics of liquid -liquid-solid fluidized bed.

Mohammed et al. used a cine camera to determine the droplet diameter and velocity of rising for three phase fluidized bed with cylindrical PVC particles and spherical plastic particles. **Hamzehei** used Syamlal-O'Brien drag function incorporated with fluent Eulerian model to investigate the hydrodynamics of gas solid fluidized bed dryer. **Han et al.** investigated the surface hydrophilicity effect of polymeric particles for three phase inverse fluidized bed. **Sivaguru et al.** employed discrete phase method to simulate the injection of air from the bottom of three phase fluidized bed and compared the results experimentally. **Jawad et al.** developed empirical correlation to predict the gas holdup in three phase slurry bubble column. **Habeeb et al.** performed experimental and simulation study for two phase fluidized bed fitted with horizontal heating tube. In this experiment we compared between pressure of the fluidized bed found experimentally and the pressure found by a two dimensional fluidized bed model that was simulated using Ansys Fluent 15.0. As well as the expansion of the bed visualized experimentally has compared with the solid volume fraction found numerically.

2. EXPERIMENTAL TEST :

An experimental rig is constructed to study the fluidized bed with 1m height and 0.0254 m diameter pipe, the solid particles placed in the test pipe and the water is pumped through the bottom of the test pipe. The equipment used for the experimental test and the measuring system is shown in figure (2), it was employed to measure the pressure of the fluidized bed along with photograph image for the solid expand.

- Perspex transparent pipe used as fluidized bed column which is 1 m height and 0.0254 m diameter.
- Square holes, rectangular pitch net with 0.334 mm spacing size act as distributor for the water as it pass from the bottom of the bed.
- Two valves and number of piping with 0.0254 m diameter.
- Flow meter that have ranges from 5 l/min to 35 l/min. Used to measure and control the volume flow rate of water.
- AOS high speed camera (SDTV 480i), active resolution of 720x480, and 29.97 Hz (59.94 Hz interlaced) image frequency. Used to report the (solid-water) flow in the test section.
- Pressure transducer sensors with a range of (0-1bar) was used to record the pressure along the test section, four sensors were used located 0.2 m apart along the test section connected to personal computer through interface.
- Pump 2″×2″ size and maximum discharge of 500 l/min used to circulate water from the water tank into the test section.
- Water tank of 760 l capacity is used to store the water.

Different values of H/D ratio and water velocity were employed in order to measure the pressure in different working conditions. The values used are shown in table (1). The experimental procedure for this work is as follows.

1. The value of spherical solid particles equal to 0.59 H/D, as shown in table (1), placed in the test pipe.
2. Water is pumped from the water tank into the test pipe with the first water flow rate equal to 5l/min as shown in table (1).
3. The volume flow rate of water entering the test pipe is measured by flow meter and is controlled by valves.
4. The pressure values is measured by pressure sensor that's connected into interface and personal computer.
5. Image for the fluidized bed pipe is taken by the high speed camera.

This procedure is repeated for the three values of water flow rate at each value of the ratio (H/D) , as shown in table (1), which produce nine experiments. To make sure of the result each experiment was repeated two or three times.
Equation (1) has used in order to show the effect of continuous phase superficial velocity

$$Q = U \, x \, A \tag{1}$$

Where A equal to the test pipe cross sectional area.

3. NUMERICAL SIMULATION :

Numerical simulation was performed for each experiment of test using ANSYS FLUENT 15.0. The model was assumed a two dimensional geometry structure modeled with Ansys Workbench 15.0, the bottom edge of the test pipe splits into 13 piece to represent the distributor. Square element mesh was employed with 0.002 m spacing size which produces 6500 element and 7014 node.

Transient, Eulerian - Eulerian, granular flow model was used according to ANSYS 13.0 help, fluent theory guide, mixture multiphase model which define the best way to model fluidized bed. Syamlal-O'Brien drag function used for the momentum exchange coefficients. K-ε, RNG mixture modeled the turbulent flow. The drag function used was chosen after testing all the drag functions coded with ANSYS FLUENT 15.0 and this one established a results that's much closer to the experimental results than the other drag functions, this producer used to select the drag function is also used to select the turbulent model.

The Inlet boundary conditions are velocity entering from the bottom of the bed (between one edge and the other) at 6 edges, the edge where no water enters modeled as zero inlet velocity entering. Outlet boundary conditions are pressure taken from the experimental test. Other parameters used in the simulation model are given in table (2).

The general equations used by Eulerian multiphase model are the conservation of mass and momentum.

3.1. Mass conservation equation

Which can be written in its general form as (2).

$$\frac{\partial}{\partial t}(\alpha_q \rho_q) + \nabla.(\alpha_q \rho_q \overrightarrow{v_q}) = \sum_{p=1}^{n}(\dot{m}_{pq} - \dot{m}_{qp}) + S_q \tag{2}$$

The source term S_q is zero as default value or else it can be a set constant value or user define.

3.2. Momentum conservation

This equation can be written in its general form as (3).

$$\frac{\partial}{\partial t}(\alpha_q \rho_q \overrightarrow{v_q}) + \nabla.(\alpha_q \rho_q \overrightarrow{v_q}\overrightarrow{v_q}) = -\alpha_q \nabla p + \nabla.\overline{\overline{\tau}}_q + \alpha_q \rho_q \vec{g} + \sum_{p=1}^{n}(\vec{R}_{pq} + \dot{m}_{pq}\vec{v}_{pq} - \dot{m}_{qp}\vec{v}_{qp})$$
$$+(\vec{F}_q + \vec{F}_{lift,q} + \vec{F}_{vm,q}) \tag{3}$$

where $\overline{\overline{\tau}}_q$ is the stress - strain tensor as (4).

$$\overline{\overline{\tau}}_q = \alpha_q \mu_q (\nabla \vec{v}_q + \nabla \vec{v}^T{}_q) + \alpha_q (\lambda_q - \frac{2}{3}\mu_q)\nabla.\vec{v}_q \overline{\overline{I}} \tag{4}$$

q represents the phase in all equations.

The setup of the experiments inserted to the ANSYS FLUENT 15.0 are shown in figure (1).

The value of the static head (H) for the solid particles on the y axis will be determined according to the ratio H/D used experimentally as shown in table (1). The inlet velocity is the water superficial velocity found using equation (1).

4. RESULTS AND DISCUTION :

4.1. Experimental results

The effect of water superficial velocity (0.16, 0.49, 0.82 m/s) and H/D ratio (0.59, 0.98, 1.38) are shown as images and pressure-length graphs. The pressure was measured at four points along the test section 20 cm separated.

A. Effect of water superficial velocity

Figure (3) shows the effect of water superficial velocity on pressure profile for different ratios of H/D. When water superficial velocity increases the pressure increased due to the increase in the density of the (solid – water) mixture, when the velocity increased the expansion of the solid particles will be increased reaching higher points inside the bed column that contain water as continuous phase. Figures (4a, 5a, 6a) shows image taken for the flow behavior in the test pipe as the water superficial velocity increases for different values of H/D ratio, from these images it's clear that the expanding of solid particles inside the bed increases as the water superficial velocity increases leading to increase in the spaces between the particles, this is one of the reasons for the increase in the pressure inside the bed.

B. Effect of H/D ratio

Figure (7) shows the effect of H/D ratio on the pressure profile at different water superficial velocities. When the solid increase inside the bed pipe the pressure increases where the solid particles take the volume that a cubed by water which increase the pressure. Figure (8a, 9a, 10a) shows images taken for the flow behavior in the test pipe as H/D increases at different values of water superficial velocity, the expanding of solid particles inside the bed increases as H/D increases which also increased the spaces between the particles.

4.2. Numerical simulation

From the 2D numerical simulation adapted in this work the volume fraction of solid particles and mixture pressure were obtained, the numerical pressure results compared with the experimental data.

Figure (3) shows a comparison between the experimental and the numerical results as the effect of water superficial velocity increasing on the pressure profile at different values of the ratio H/D. The numerical results were taken at the same point coordinate where the pressure sensor located experimentally, there is small difference between the numerical and the experimental results (between 0 - 16%) since the model is two dimensional and the flow entering into the test section is different than in the actual experiment. Figures (4, 5, 6) Shows a visual comparison between the solid volume fraction found numerically and the image taken from movie captured by high speed camera as the water superficial velocity increases, the contour color was set to be the same for all experiment simulation so one can see the difference in the solid packing as the velocity increases. Figure (7) shows a comparison between the experimental and the numerical results as the effect of H/D increasing at different values of water superficial velocity. Figures (8, 9, 10) shows a visual comparison between the solid volume fraction found numerically and the image taken from movie captured by high speed camera as H/D increases. The difference between the experimental and numerical images may due to the difference in time in which it taken, all the images found numerically are taken at the same time which is 2.5 sec meanwhile the experiment images are taken at different times ranging from 1 to 4 sec.

5. CONCLUSION :

This work represented an experimental and computational fluid dynamic study of pressure and flow behavior in a fluidized bed. Stainless steel spherical particles with 1.5 mm diameter were used as solid phase. Pressure was measure at four locations along the test section. The flow behavior was photograph using high speed camera. Concluding remarks are summarized below.

- When the water superficial velocity increases the static pressure increases along the bed column.
- When H/D ratio increases the static pressure along the bed column will increases.
- When water superficial velocity increases the spaces between the solid particles increases as the expansion of the solid particles increased.
- When H/D increases the expansion of the solid particles will increase leading to increase in the spaces between the solid particles.

Table 1: Working conditions values.

H/D ratio	Water flow rate (l/min)	Water superficial velocity (m/s)
0.59	5	0.16
0.98	15	0.49
1.38	25	0.82

Table 2. Simulation parameter.

Description	Value
Particle density	8000 kg/m^3
Water density	998.2 kg/m^3
Mean particle diameter	1.5 mm
Initial solids packing	0.7668
Superficial water velocity	0.16, 0.49, 0.82 m/s
Bed height	1 m
Bed width	0.0254 m
Static bed height (H)	0.015, 0.025, 0.035 m
Time steps	0.0007 sec
Maximum iteration	20
Pressure under relaxation	0.3
Momentum under relaxation	0.2
Volume fraction under relaxation	0.5

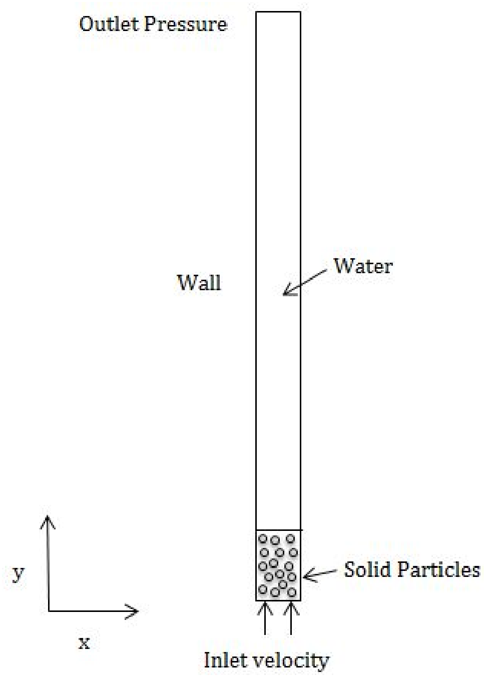
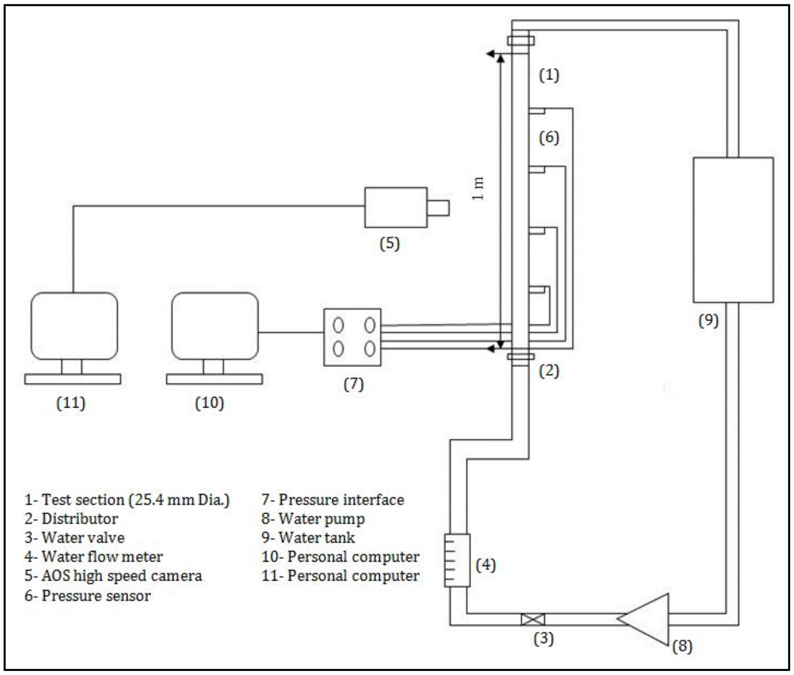


Fig. 1: The fluidized bed column setup with 1 m height and 0.0254 m diameter.



a- Schematic diagram

b- Experimental rig

Fig. 2: Experimental rig and schematic diagram for the experiment

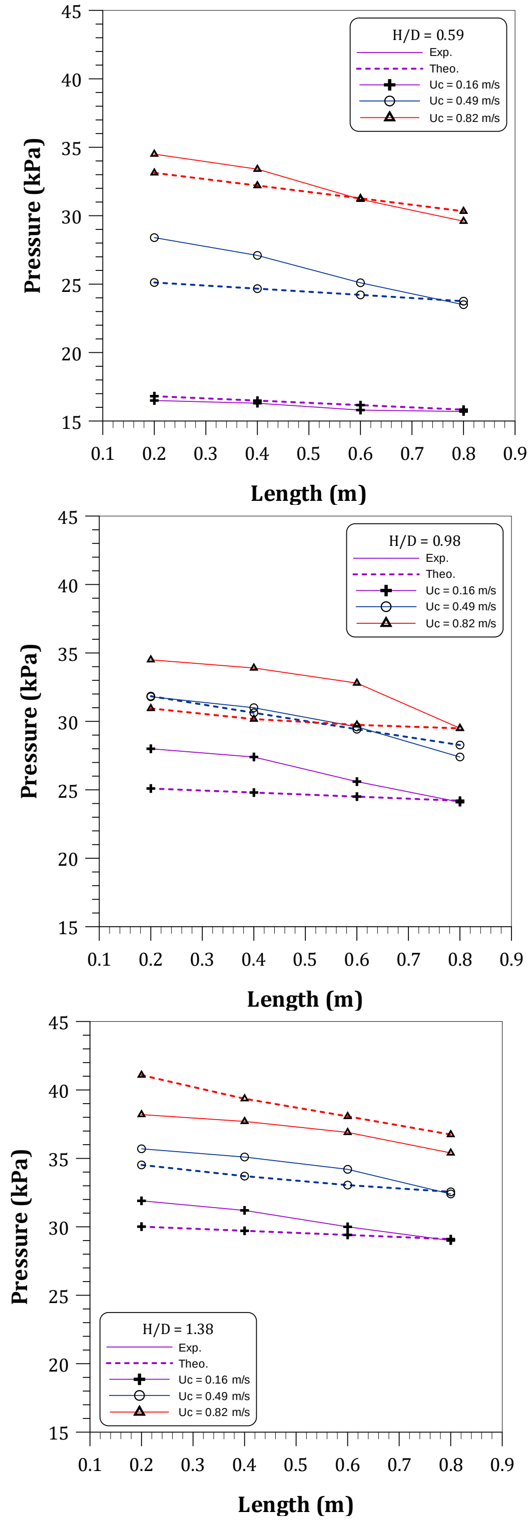
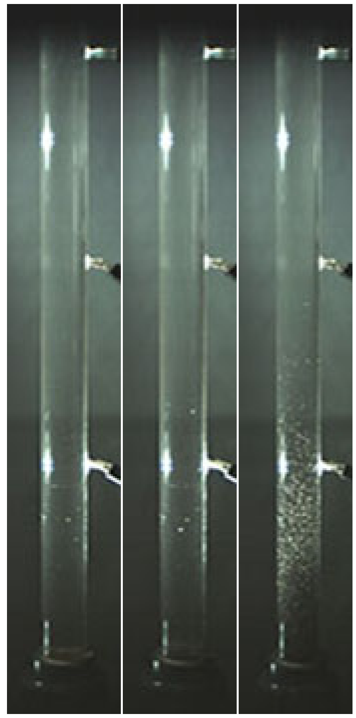
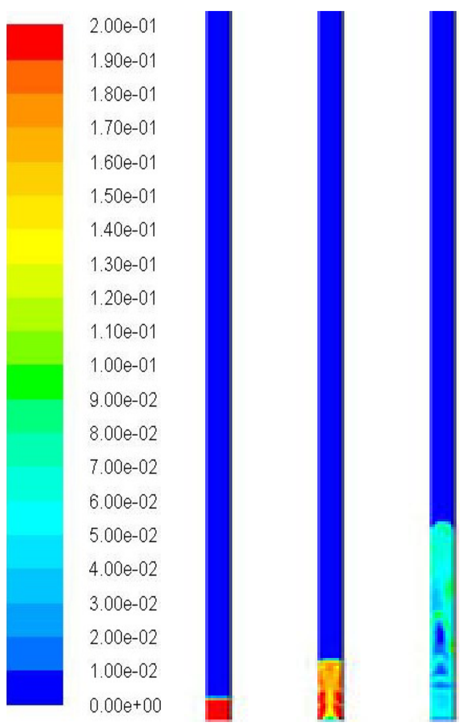


Fig. 3: Effect of water superficial velocity on pressure profile along the pipe.



Uc(m/s) 0.16 0.49 0.82

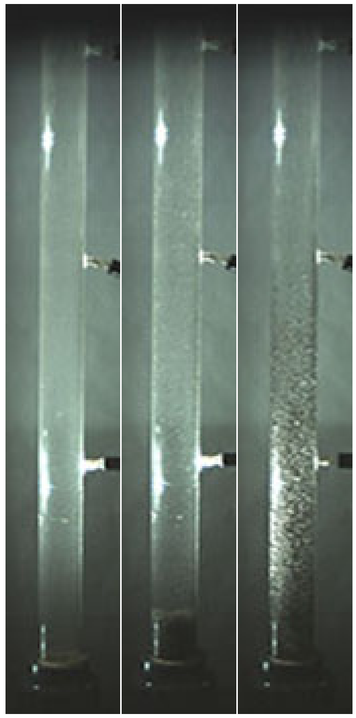
a- Experimentally



Uc (m/s) 0.16 0.49 0.82

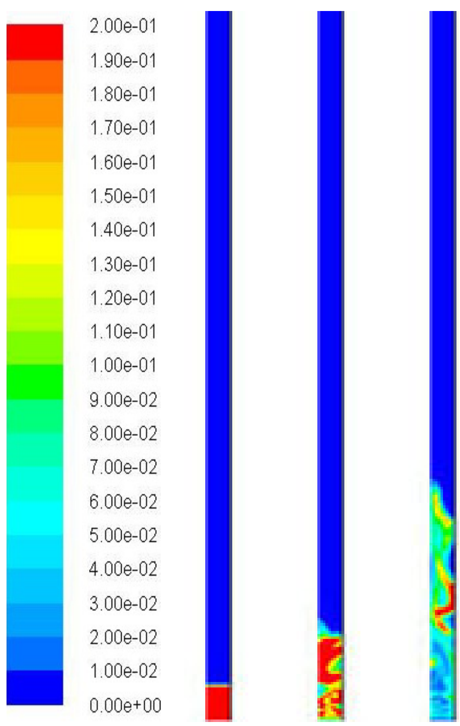
b- Numerically

Fig. 4: Effect of water superficial velocity on the solid volume fraction at 0.59 H/D



Uc(m/s) 0.16 0.49 0.82

a- Experimentally



Uc (m/s) 0.16 0.49 0.82

b- Numerically

Fig. 5: Effect of water superficial velocity on the solid volume fraction at 0.98 H/D

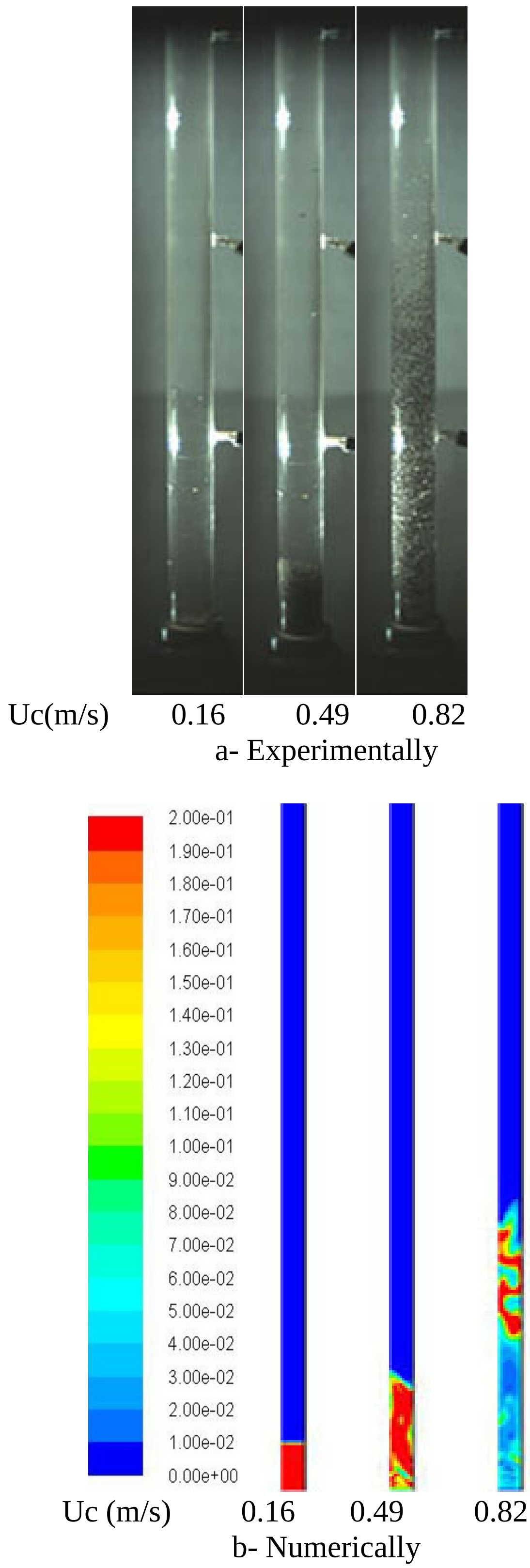
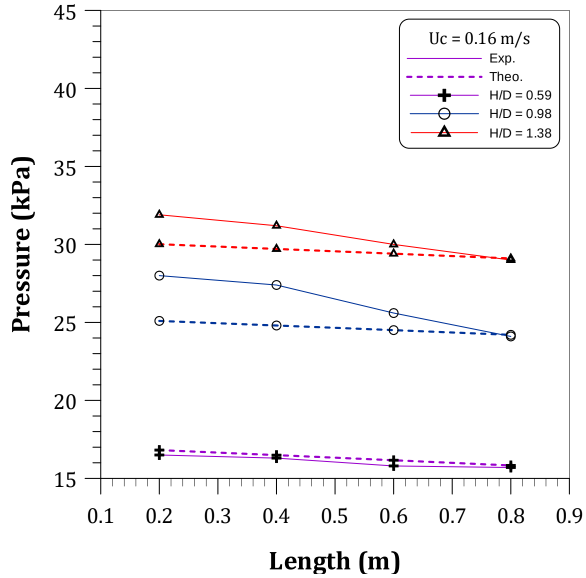
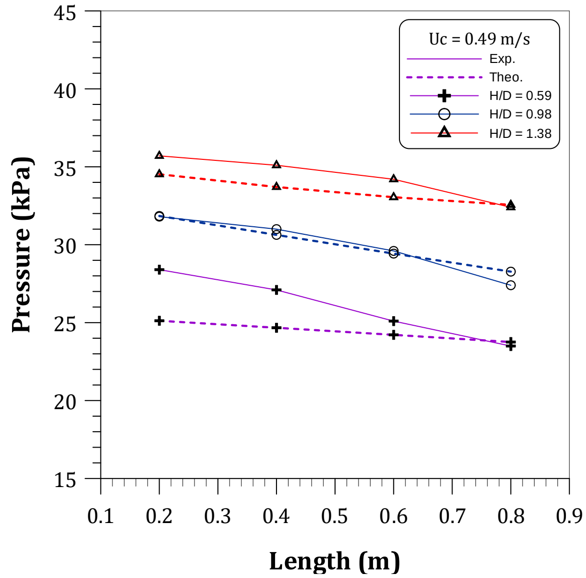


Fig. 6: Effect of water superficial velocity on the solid volume fraction at 1.38 H/D


Uc = 0.16 m/s
Exp.
Theo.
H/D = 0.59
H/D = 0.98
H/D = 1.38
Pressure (kPa)
Length (m)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Exp.
Theo.
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H/D = 0.98
H/D = 1.38
Pressure (kPa)
Length (m)

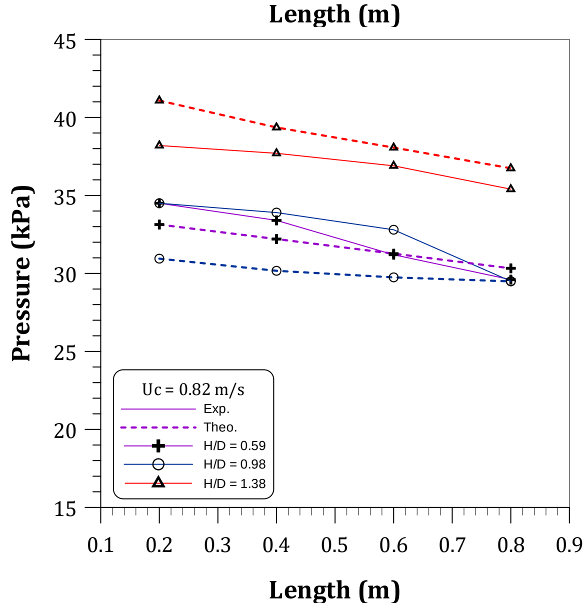
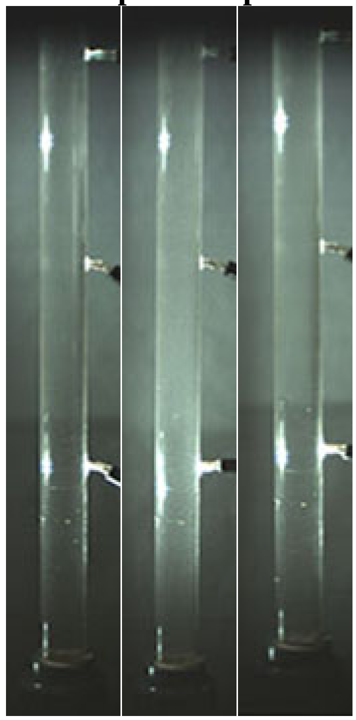
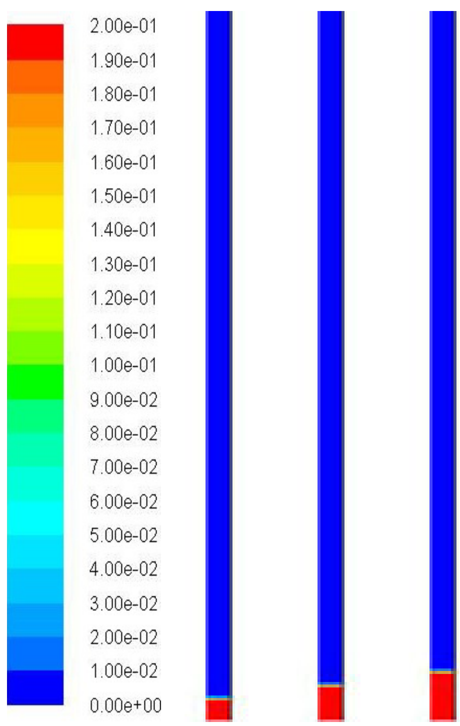

Uc = 0.82 m/s
Exp.
Theo.
H/D = 0.59
H/D = 0.98
H/D = 1.38
Pressure (kPa)
Length (m)

Fig. 7: Effect of H/D on pressure profile along the pipe.



H/D 0.59 0.98 1.38

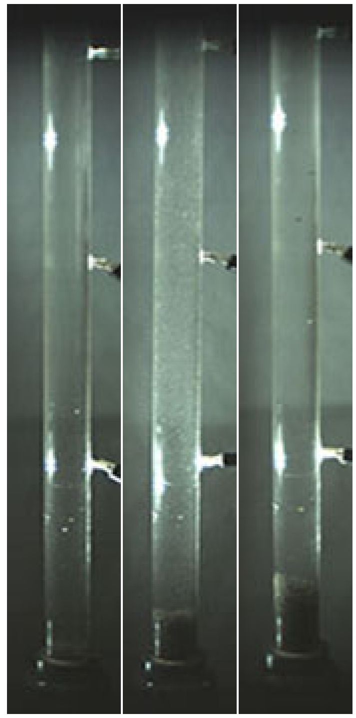
a- Experimentally



H/D 0.59 0.98 1.38

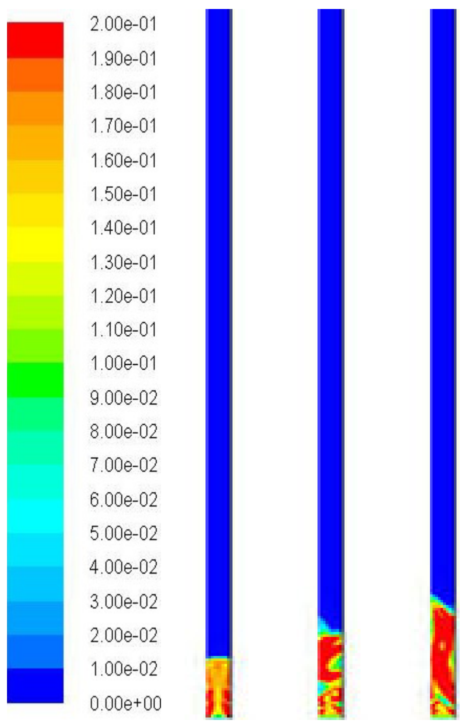
b- Numerically

Fig. 8: Effect of H/D on the solid volume fraction at 0.16 m/s water superficial velocity



H/D 0.59 0.98 1.38

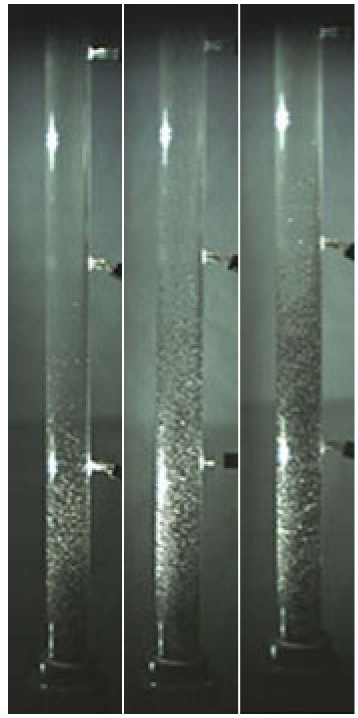
a- Experimentally



H/D 0.59 0.98 1.38

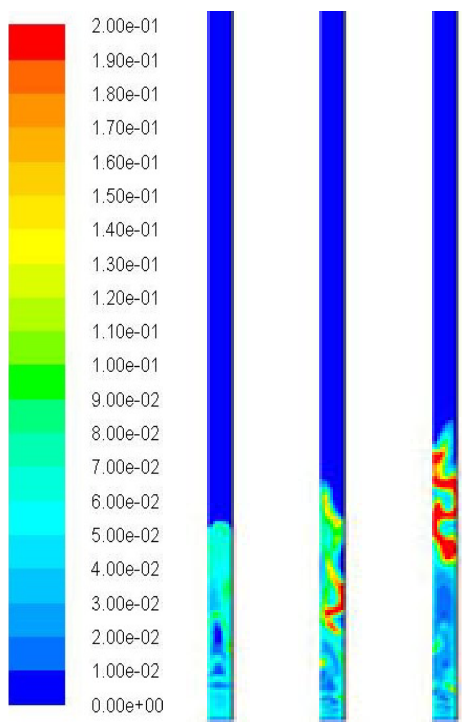
b- Numerically

Fig. 9: Effect of H/D on the solid volume fraction at 0.49 m/s water superficial velocity



H/D 0.59 0.98 1.38

a- Experimentally



H/D 0.59 0.98 1.38

b- Numerically

Fig. 10: Effect of H/D on the solid volume fraction at 0.82 m/s water superficial velocity

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